NACA TN 3976

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3976

RUPTURE STRENGTH OF SEVERAL NICKEL-BASE ALLOYS IN SHEET FORM

By James H. Dance and Francis J. Clauss

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

Washington
April 1957

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3976

RUPTURE STRENGTH OF SEVERAL NICKEL-BASE ALLOYS IN SHEET FORM

By James H. Dance and Francis J. Clauss

4341

SUMMARY

An investigation was conducted to determine the 100-hour rupture strengths at 1200° and 1350° F of Inconel X, Inconel 700, Incoloy 901, Refractaloy 26, and R-235 sheet alloys in both the annealed and heat-treated conditions. The strongest alloys at 1200° F were Inconel 700 and Incoloy 901 in the heat-treated condition, with strengths of 77,500 and 76,500 psi, respectively. At 1350° F, the strongest alloys were heat-treated Inconel 700 and R-235 with respective 100-hour strengths of 57,500 and 53,500 psi. Incoloy 901 in the annealed condition was the most ductile with an elongation in stress-rupture of 6 to 20 percent. In both the annealed and heat-treated conditions, the other alloys elongated only about 1 to 5 percent. Photomicrographs show that fractures occur predominantly in the grain boundaries. The strengths of these alloys are compared with published data for other sheet alloys and bar stock.

CW-1

INTRODUCTION

Current trends in jet engine design are to increase airflow and gas temperatures. These result in higher stresses and temperatures in turbine blades, which are already operating near the limit of the strength of current blade alloys. Cooling the blades to temperatures where the material is stronger will enable the blades to operate in hotter gas streams and withstand the higher stresses imposed by increased flow.

Some of the most promising designs of cooled turbine blades have shells made from sheet (ref. 1). Air is blown through the blades to lower the metal temperature to a value where its strength is sufficient. Designers estimate that some blades may require an operating temperature as low as 1200° F.

Cobalt- and nickel-base "superalloys" are widely used for conventional cast and forged blades which operate at temperatures of approximately 1500° F. Many of these alloys and several experimental nickel-base alloys have recently become available in sheet form and are being considered for cooled turbine blades. While at present very limited published data are available on these nickel-base sheet alloys at the lower temperatures, bar stock and sheet data for higher temperatures suggest that these alloys may be stronger at 1200° F than other sheet alloys.

Alloys of this general class are frequently weaker in sheet form than in bar form, and predictions of sheet strength based on that of bar stock are subject to large error. Likewise, extrapolations of sheet data from high to low temperature are often in error, so that actual test results are needed for the sheet alloys at lower temperatures.

The purposes of this study are to determine the 100-hour rupture strength for several nickel-base sheet alloys at temperatures that might be reached in cooled turbine blades, namely 1200° and 1350° F, and to compare these strengths with those of other oxidation resistant materials available in sheet form.

The alloys evaluated were: Inconel X, Inconel 700, Incoloy 901, R-235, and Refractaloy 26. Some data on Inconel X and Incoloy 901, which were published very recently, are included for comparison.

PROCEDURE

Materials

The alloys were selected on the basis of existing data and their availability in sheet form. The nominal compositions of the alloys evaluated, Inconel X, Inconel 700, Incoloy 901, R-235, and Refractaloy 26, are listed in table I. All specimens of each alloy were taken from a single heat of material.

The sheet was received in the annealed condition and varied in thickness from 0.038 to 0.050 inch, depending on the alloy. Since these alloys are all precipitation-hardening, their maximum strengths should be developed by heat-treatment. However, sheet parts are generally fabricated and used in the annealed condition. This is because the fabrication is most satisfactorily accomplished in the annealed condition and the parts are too large to be heat-treated or because there is danger of warpage from heat-treatment after fabrication. On the other hand, small parts such as sheet turbine blades can be heat-treated after fabrication. Each alloy was therefore evaluated in stress-rupture in both the annealed and the solution-treated and aged conditions. The heat-treatments used were those recommended by the manufacturer for sheet and are listed in table II. An argon atmosphere was used in heat-treatment to minimize surface corrosion.

4541

Specimen

The specimen and gripping arrangement are shown in figure 1. The specimens conformed to the ASTM standard sheet metal tensile specimen for ferrous materials (ref. 2). The gripped ends of the specimens extended 3 to 4 inches outside the stress-rupture furnaces. Reinforcements were welded to the ends of the 11/16-inch-wide specimens to insure against failure at the loading pins.

The edges of the test sections were ground to shape and hand finished with 4/0 emery paper to the tolerances shown in figure 1. The flat surfaces were those produced by rolling. All specimens were cut with their axes parallel to the direction of final rolling.

Stress-Rupture Evaluation

Tests were run at 1200° and 1350° F in conventional stress-rupture equipment. The stresses were selected to permit accurate determination of the 100-hour lives.

Thermocouples were tied with 0.010-inch stainless steel wire to the specimen surface at the center and ends of the test section. The center was maintained within $\pm 5^{\circ}$ F of the test temperature and the ends within $\pm 5^{\circ}$ F of the center. The total elongation in the 2-inch gage section was determined after fracture from the increase in distance between the shoulders of the reduced section of the specimens. In several cases, the nature of the fracture made it impossible to determine the elongation.

Metallographic and Hardness Evaluation

Representative photomicrographs were made of the alloys in the following conditions: (1) annealed, (2) heat-treated, and (3) both conditions after fracture in approximately 100 hours. Rockwell A- hardness was measured on the same specimens.

RESULTS AND DISCUSSION

Curves of stress plotted against the logarithm of time to rupture for each alloy are shown in figure 2. Where available, percent elongation is indicated by the numbers next to the data points. The 100-hour rupture strengths determined from these curves are listed below and compared in the bar graph in figure 3:

	100-Hour rupture strength at 1200° F, psi		100-Hour rupture strength at 1350° F, psi	
	Annealed	Heat-treated	Annealed	Heat-treated
Inconel X	53,500	63,500	37,000	42,000
Inconel 700	72,000	77,500	54,000	57,500
Incoloy 901	73,000	76,500	43,500	42,500
R-235	60,500	70,000	47,000	53,500
Refractaloy 26	62,000	68,000	35,000	35,000

At 1200° F, the strengths of all five alloys were increased by heat-treatment, while at 1350° F, the strengths of only Inconel X, Inconel 700, and R-235 were increased. The increase in strength is most marked for R-235 alloy. Incoloy 901 appears to be weaker at 1350° F after heat-treatment, but the loss in strength is slight and may be due to the scatter of the data.

Incoloy 901 in the annealed condition elongated from 6 to 20 percent, while the other alloys elongated only about 1 to 5 percent.

Photomicrographs and hardness values for annealed, heat-treated, and stress-rupture tested material are shown in figure 4. The hardness of the annealed material was increased both by heat-treatment and by testing in stress-rupture. All alloys fractured predominantly along the grain boundaries. Failure was accompanied by more grain separation in Inconel X and Incoloy 901 than in the other alloys. There was also a pronounced increase in general precipitation within the grains in Inconel X after heat-treatment.

The highest values of the 100-hour rupture strengths from figure 3 are compared in figures 5(a) and (b) with published data for a number of sheet materials tested at 1200° and 1350° F. The values determined in this study and those reported in the literature for Inconel X and Incoloy 901 are in general agreement. The small differences may be due to heat-to-heat variations in composition, differences in heat-treatment, testing procedures, and so forth.

4341

At 1200° F, Inconel 700, Incoloy 901, and R-235 have higher 100-hour rupture strengths than those of any other oxidation resistant sheet alloys for which data are available, while at 1350° F, Inconel 700 and R-235 are far stronger than any others.

Incoloy 901 has the highest iron and lowest chromium content and is the least strategic material of the alloys evaluated. It suffered a large loss of strength when the testing temperature was raised from 1200° to 1350° F. However, Incoloy 901 is stronger than S-816 and HS-21, the best of the cobalt-base sheet alloys at 1350° F. Refractaloy 26 and Inconel X, which are also much less strategic than cobalt-base alloys, are about as strong as S-816 and HS-21 at 1200° and 1350° F.

The 100-hour rupture strengths for heat-treated sheet alloys are compared in figure 6 with values published for bar stock. The results show that although the heat-treatment improves the strength in most cases, the sheet is weaker than bar stock. Note that the heat-treatments given sheet and bar stock of the same alloy are not usually the same. To prevent excessive grain growth, the solution temperatures for sheet are often limited.

CONCLUDING REMARKS

The 100-hour rupture strengths of five nickel-base alloys (Inconel X, Inconel 700, Incoloy 901, R-235, and Refractaloy 26) in sheet form were determined at 1200° and 1350° F. The results show that:

1. The best nickel-base sheet alloys have greater 100-hour rupture strengths at 1200° and 1350° F than other oxidation resistant sheet alloys for which data are available.

2. Of the nickel-base alloys studied, Inconel 700 and Incoloy 901 were strongest at 1200° F. The strongest alloys at 1350° F were Inconel 700 and R-235.

3. The precipitation-hardening heat-treatments used in this investigation strengthened all five alloys when tested at 1200° F, while at 1350° F only Inconel X, Inconel 700, and R-235 were strengthened.

4. Nickel-base sheet alloys generally lack the ductility of cobalt- and iron-base sheet alloys. Incoloy 901, which in the annealed condition elongated up to 20 percent in stress-rupture tests, was the most ductile; the remaining nickel-base alloys elongated only about 1 to 5 percent.

5. Stress-rupture fractures generally occurred in the grain boundaries.

6. Heat-treatment raises the strength of sheet in most cases, although not to the level of heat-treated bar stock. The recommended heat-treatments for bar stock and sheet of the same alloy, however, are often not the same.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, January 28, 1957

4341

REFERENCES

1. Ault, G. Mervin, and Deutsch, George C.: Review of Materials for Jet Engines. NACA-University Conference on Aerodynamics, Construction, and Propulsion. Vol. I - Aircraft Structures and Materials. Lewis Flight Propulsion Lab., Nat. Advisory Committee for Aero., Oct. 1954.

2. Anon.: Tentative Methods of Tension Testing of Metallic Materials. ASTM Designation: E8-54T, ASTM Standards, 1955, pp. 1551-1565.

3. Anon.: INCO Current Data Report No. 5. The International Nickel Co., Inc., Apr. 1955.

4. Anon.: INCO Current Data Report No. 7. The International Nickel Co., Inc., Mar. 1956.

5. Anon.: Hastelloy Alloy R-235. Haynes Stellite Co., July 1956.

6. Anon.: Wrought High Temperature Alloys - Discaloy - Refractaloy - K42B. Tech. Data Sheet 52-200, Westinghouse Electric Co., Nov. 1954.

7. Doerr, D. D.: Determination of Physical Properties of Ferrous and Nonferrous Structural Sheet Materials at Elevated Temperatures. AF Tech. Rep. No. 6517, pt. 2, Wright Air Dev. Center, Air Res. and Dev. Command, United States Air Force, Wright-Patterson Air Force Base, Apr. 1954. (Contract No. AF33 (038)-8681, RDO No. 614-13.)

8. Simmons, Ward F., and Cross, Howard C.: The Elevated-Temperature Properties of Selected Super-Strength Alloys. Spec. Tech. Pub. No. 160, ASTM, 1954.

9. Anon.: Wrought Alloy for High Temperature Service - Haynes Alloy No. 99. Haynes Stellite Co., July 22, 1952.

10. Preston, D.: Exploratory Investigation of High-Temperature Sheet Materials. Proc. ASTM, vol. 52, 1952, pp. 962-986; discussion, p. 986.

11. Perlmutter, I., and Rector, W. H.: Investigation of Sheet Materials for Application at High Temperatures. AF Tech. Rep. 5712, United States Air Force, Air Materiel Command, Wright-Patterson Air Force Base, July 13, 1948.

12. Anon.: Hastelloy Alloy X. F-7989, Haynes Stellite Co., June 1952.

13. Anon.: Inconel "X" - A High Strength, High Temperature Alloy. Dev. and Res. Div., The International Nickel Co., Inc., Jan. 1949.

14. Anon.: Preliminary Technical Data on Allegheny Ludlum Alloy V-36. Watervliet Res. Lab., Allegheny Ludlum Steel Corp., July 10, 1950.

15. Anon.: Two New Alloys for High Temperature Service. Mech. Topics, vol. 17, no. 2, July 1956, p. 11.

TABLE I. - CHEMICAL COMPOSITIONS, PERCENT BY WEIGHT

Alloy	Analysis	C	Fe	Cr	Ni	Co	Mo	Ti	Al	Mn	Si	Cu	S	Nb+Ta
Inconel X	Nominal	0.04	7.0	14.5	73.0			2.5	0.70	0.50				1.00
	Vendor's (heat 4893X)	0.05	6.46	15.15	73.09			2.48	0.82	0.71	0.40	0.03	0.007	0.78
Inconel 700	Nominal	[a]0.16	[a]4.0	13.0-17.0	Bal-ance	24.0-34.0	1.0-4.5	1.75-2.75	2.5-3.5	[a]2.0	[a]1.0	[a]0.5	[a]0.015	
	Vendor's (heat 7953)	0.11	0.42	15.51	45.48	29.8	3.21	2.19	3.0	0.09	0.19	0.02	0.007	
Incoloy 901	Nominal		Bal-ance	11.0-14.0	40.0-45.0		5.0-7.0	2.0-3.0						
	Vendor's (heat Y-7983)	0.05	35.02	12.77	43.15		5.68	2.43	0.15	0.48	0.22	0.02	0.007	
Refractaloy 26	Nominal	0.05	17.5	18.0	37.0	20.0	3.0	2.8	0.20	0.70	0.80			
	Vendor's (heat R-669)	0.031	16.6	18.4	37.1	20.3	3.05	2.43	0.06	0.83	0.91			
R-235	Nominal	[a]0.16	9.0-11.0	14.0-17.0	66.0	[a]2.5	4.5-6.5	2.25-2.75	1.75-2.25	[a]1.0	[a]1.0			

[a]Maximum.

TABLE II. - HEAT-TREATMENTS

Material and vendor	Vendor's annealing treatment			Solution treatment			Aging treatment		
	Time, min	Temp., °F	Cooling	Time, hr	Temp., °F	Cooling	Time, hr	Temp., °F	Cooling
Inconel X (International Nickel Co. (ref. 3))	20	1950	Water	1/2	1950	Air	20	1300	Air
Inconel 700 (International Nickel Co. (ref. 3))	20	1950	Water	1/2	1950	Air	4	1600	Air
Incoloy 901 (International Nickel Co. (ref. 4))	10	2000	Water	1/2	1950	Air	2	1400	Air
R-235 (Haynes Stellite Co. (ref. 5))	15	2150	Air	1/2	2150	Air	1/3	1600	Air
Refractaloy 26 (Westinghouse Electric Co. (ref. 6))	20	1800	Water	[a]1/2	1800	Oil	44	1350	Air
				[b]1	1950	Oil	4 20	1500 1350	Air Air

[a]For tests at 1200° F.
[b]For tests at 1350° F.

Alloy	T	A	L	R	W	G
Inconel X	0.040	$\frac{11}{16}$	18	3.000±0.002	0.500±0.002	2.000±0.001
Inconel 700	0.047					
Incoloy 901	0.050					
R-235	0.038	1	20	1.250±0.002	0.500±0.002	2.000±0.001
Refractaloy 26	0.042					

Edges of test section parallel to ±0.005 in.

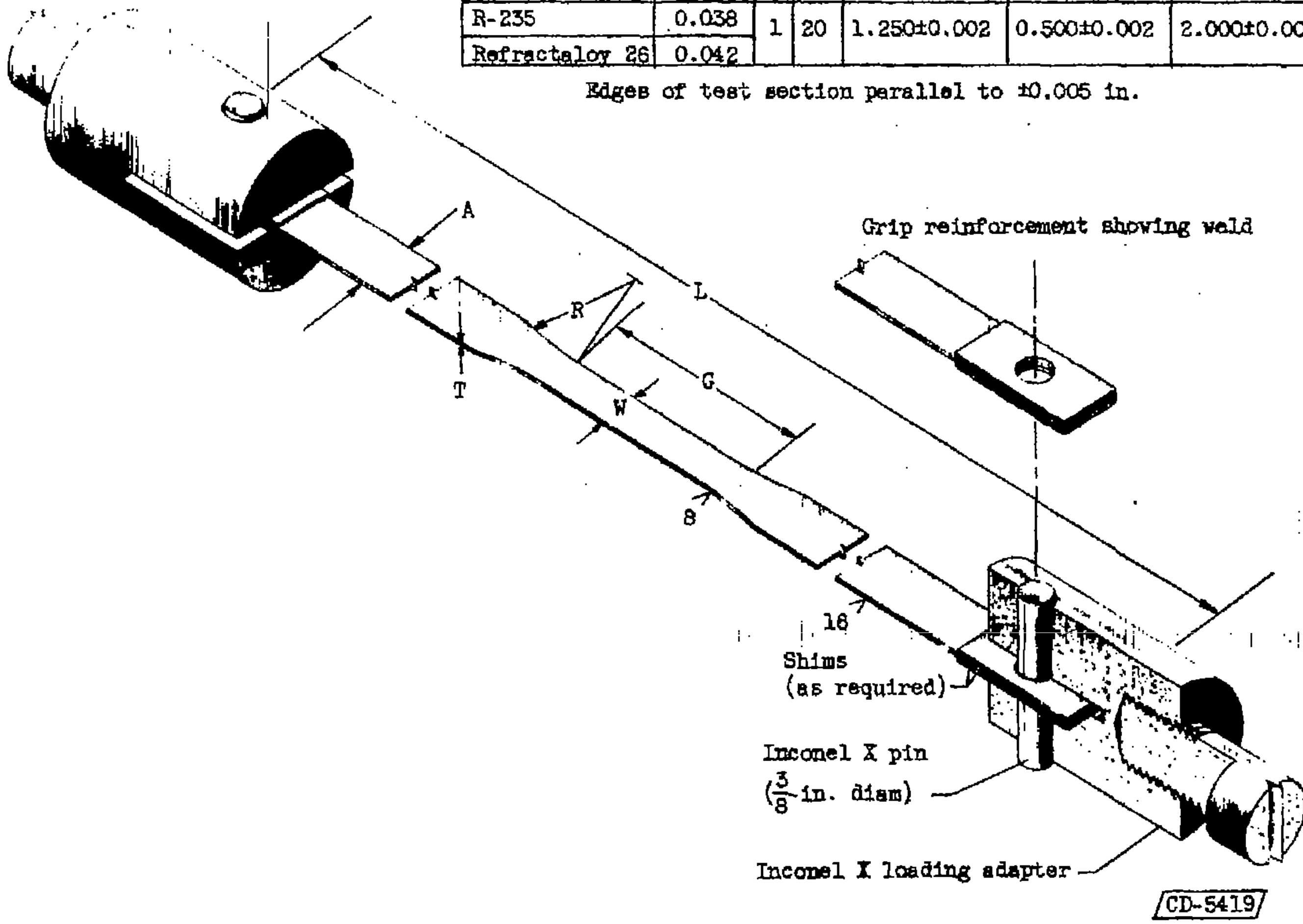
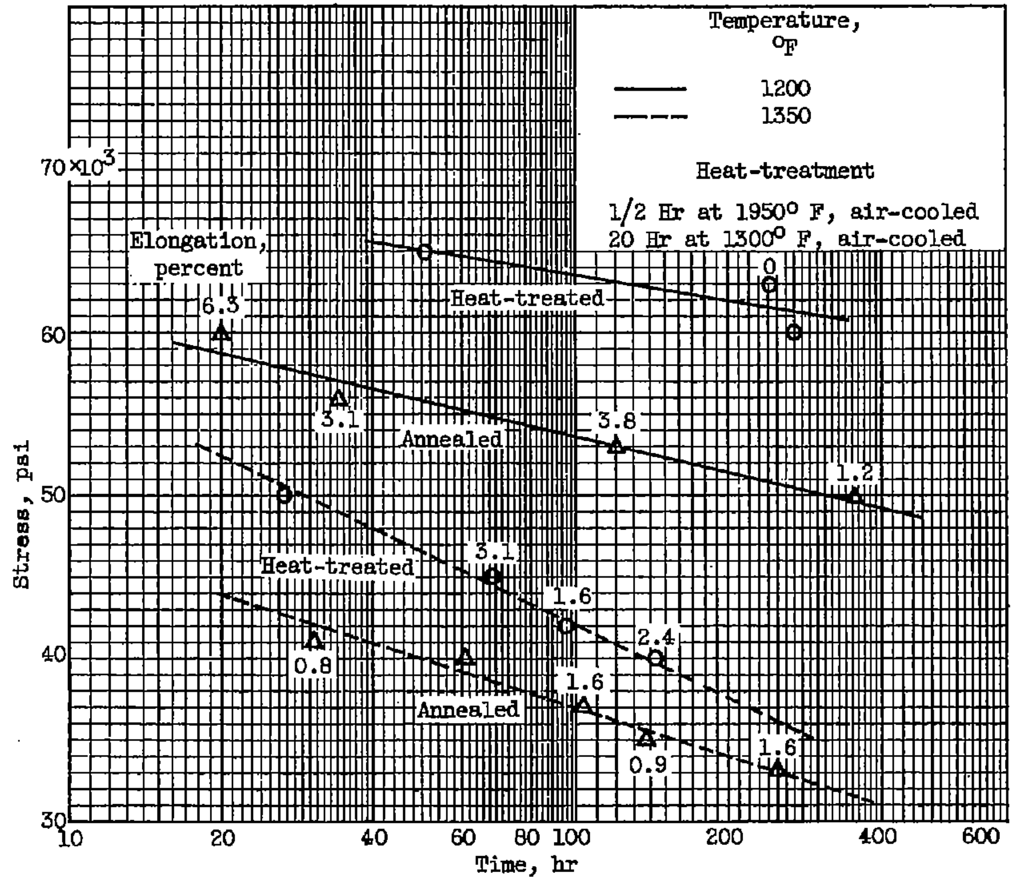
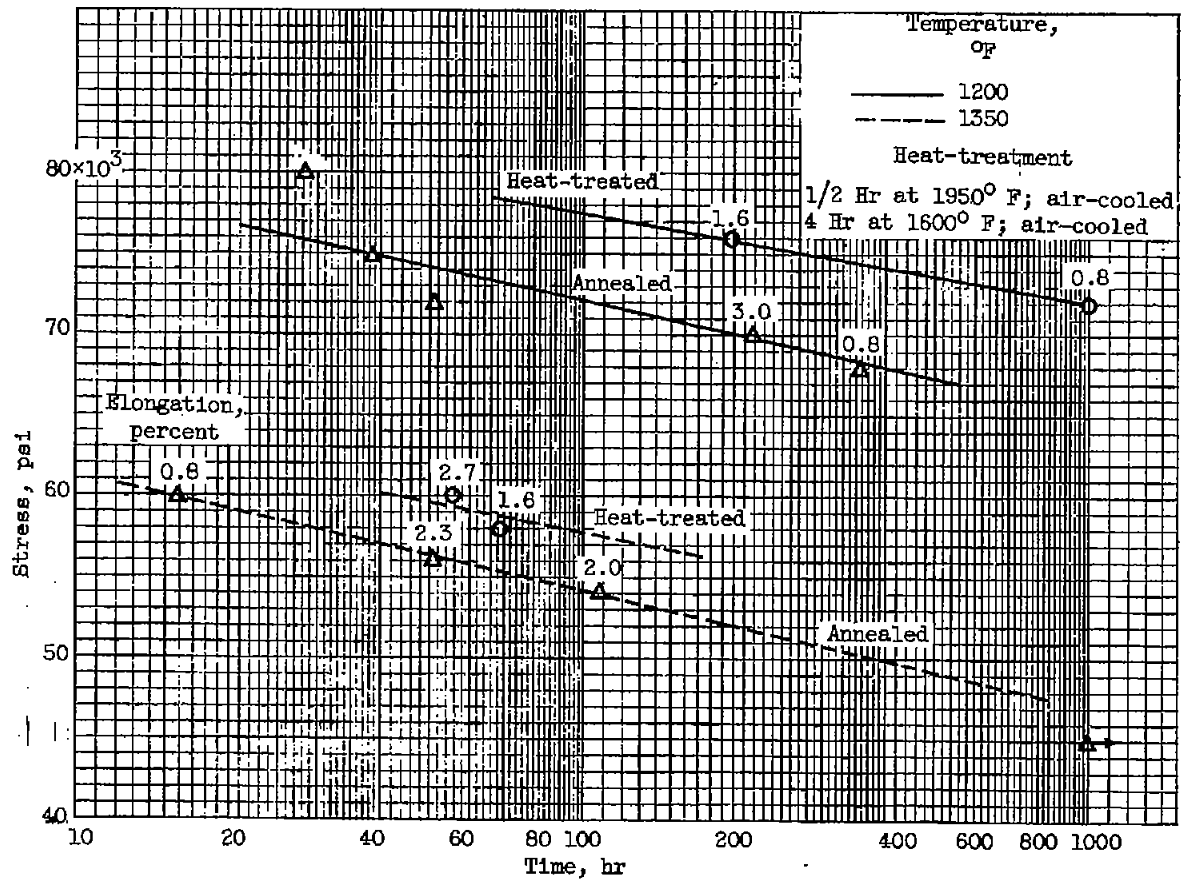


Figure 1. - Schematic diagram of stress-rupture specimen and loading adapter. (All dimensions in inches.)



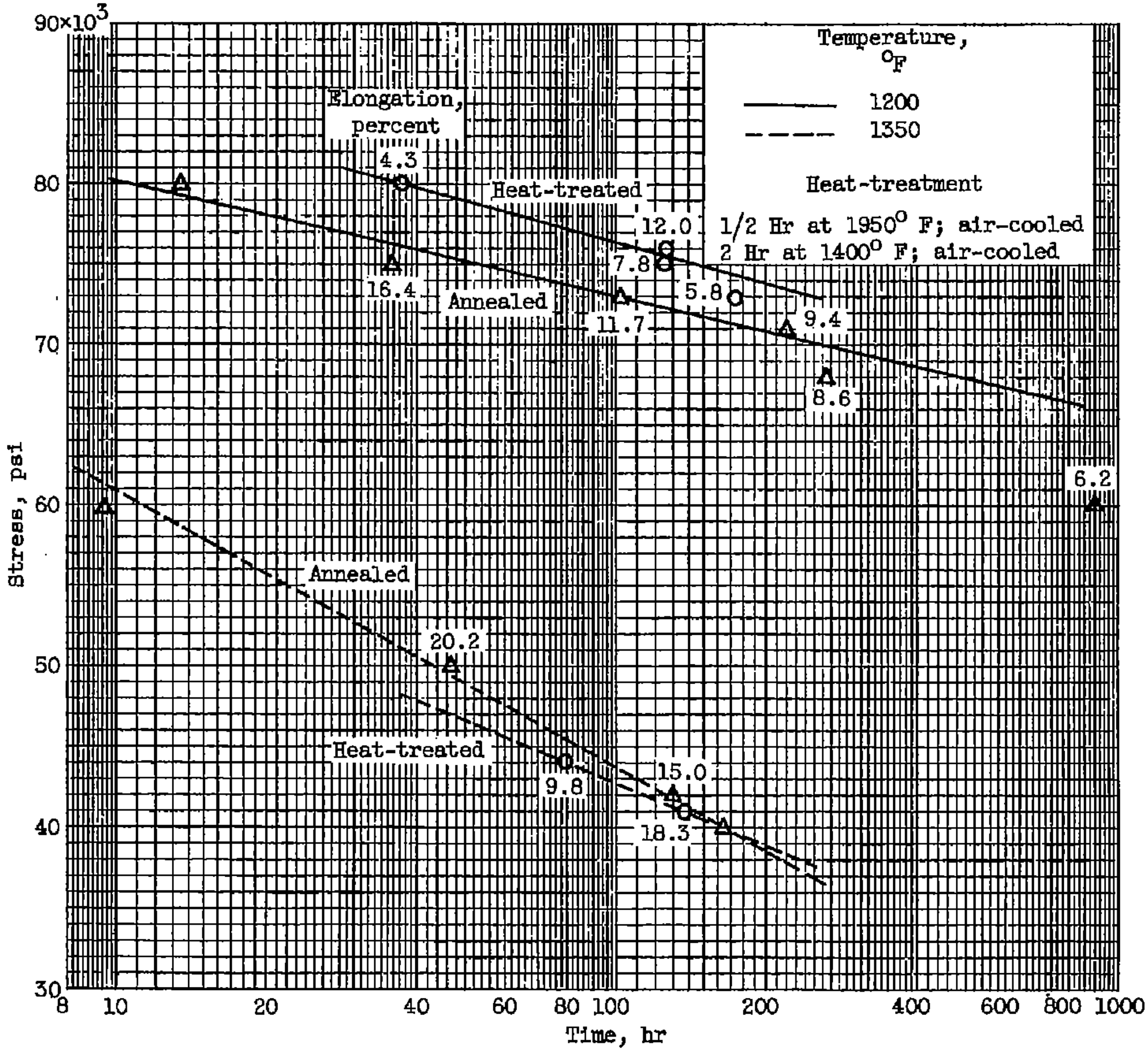
(a) Inconel X, 0.040 inch thick.

Figure 2. - Stress-rupture life of nickel-base sheet alloys at 1200° and 1350° F.



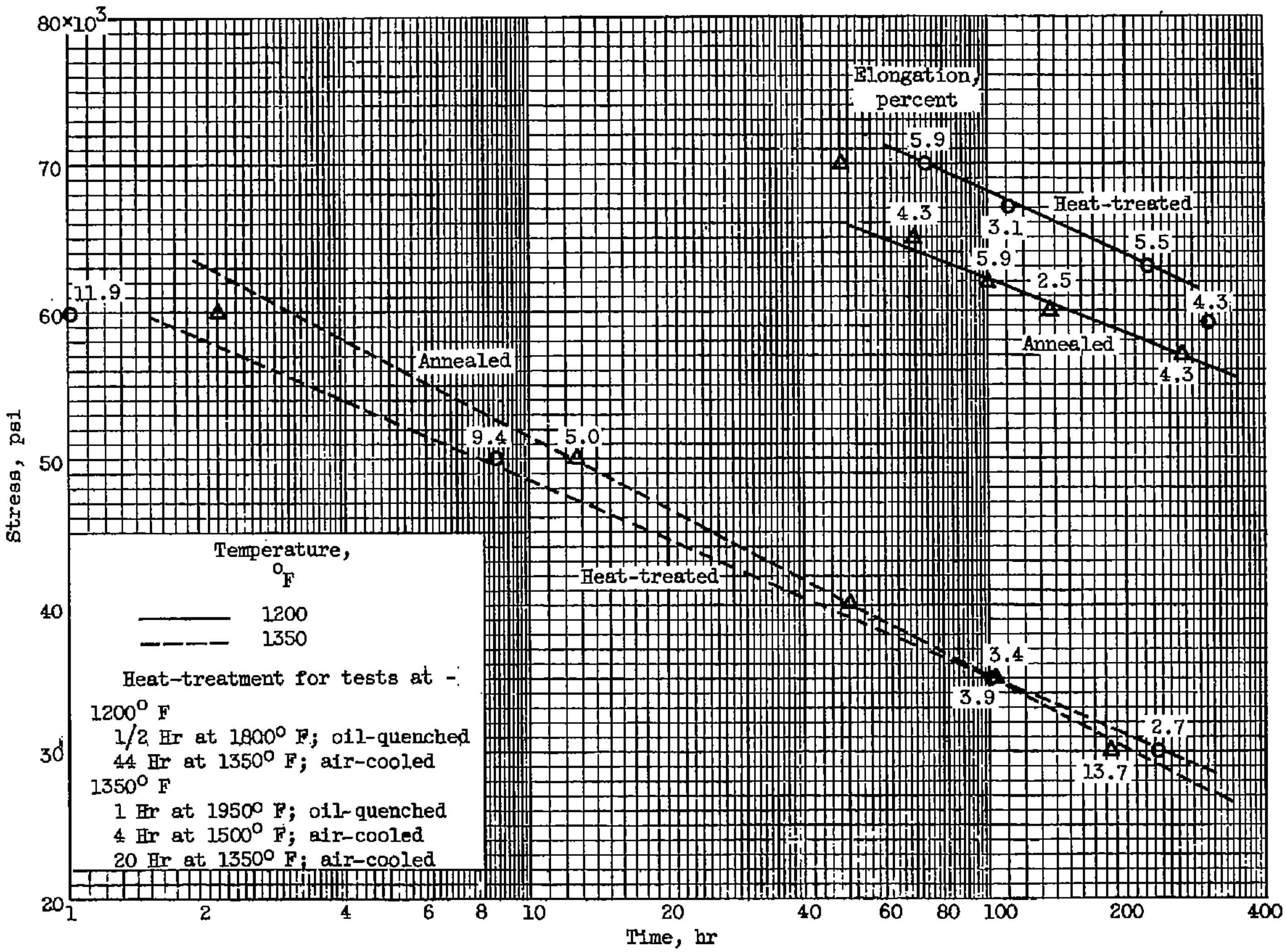
(b) Inconel 700, 0.047 inch thick.

Figure 2. - Continued. Stress-rupture life of nickel-base sheet alloys at 1200° and 1350° F.



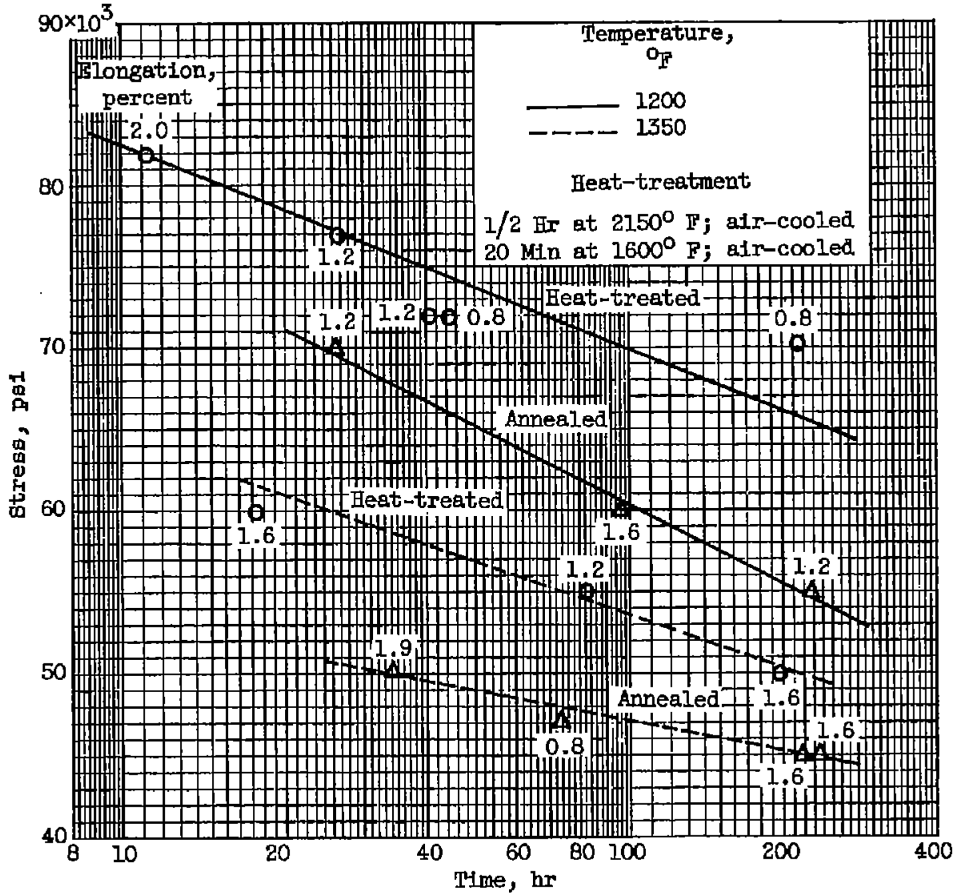
(c) Incoloy 901, 0.050 inch thick.

Figure 2. - Continued. Stress-rupture life of nickel-base sheet alloys at 1200° and 1350° F.



(d) Refractaloy 26, 0.042 inch thick.

Figure 2. - Continued. Stress-rupture life of nickel-base sheet alloys at 1200° and 1350° F.



(e) R-235, 0.038 inch thick.

Figure 2. - Concluded. Stress-rupture life of nickel-base sheet alloys at 1200° and 1350° F.

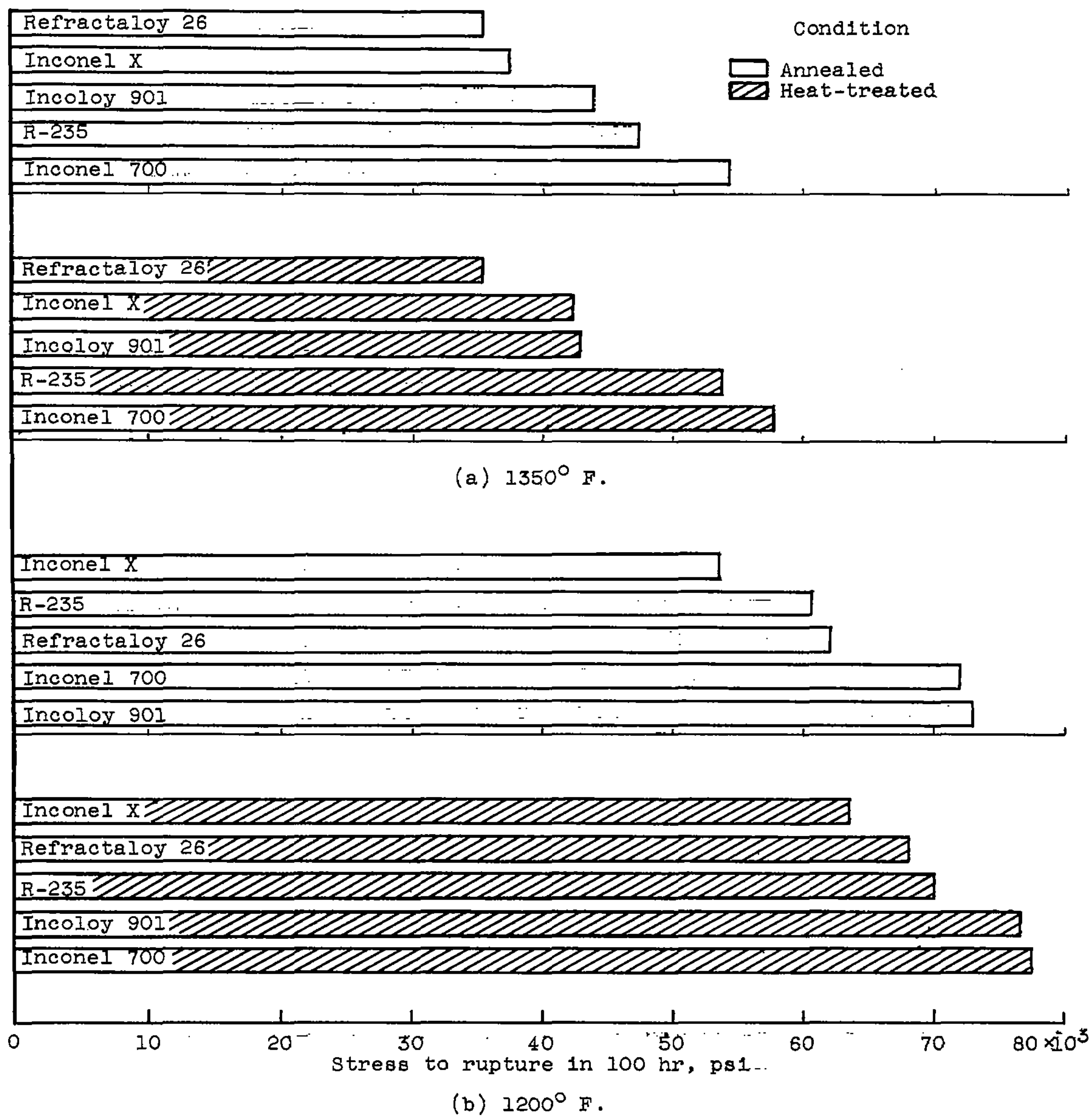
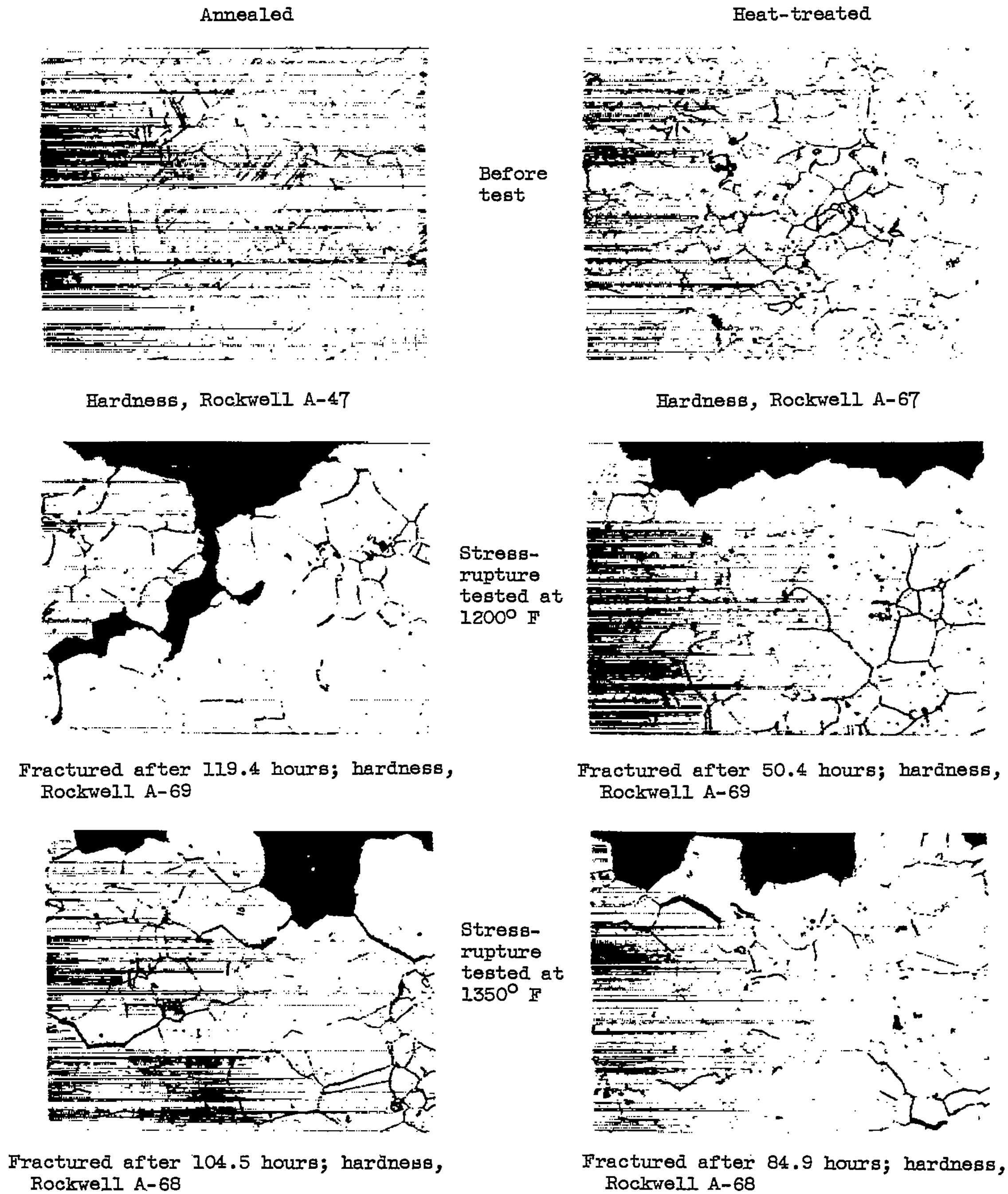


Figure 3. - Comparison of 100-hour rupture strengths of nickel-base sheet alloys at 1200° and 1350° F.

4341



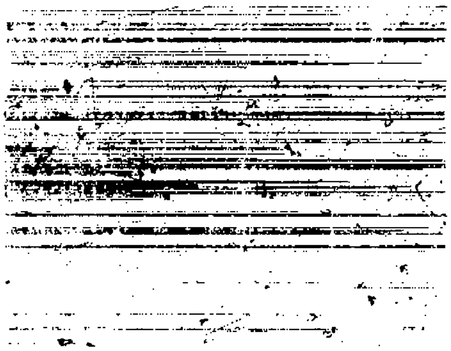
C-44048

(a) Inconel X. Etchant, 50 parts water, 40 parts hydrochloric acid, 10 parts nitric acid.

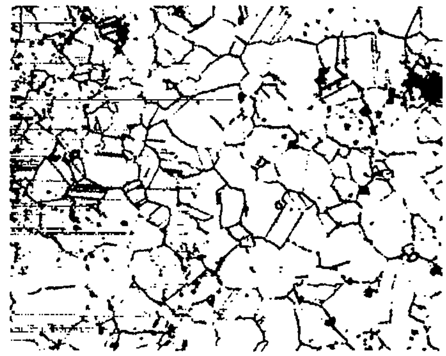
Figure 4. - Microstructures of nickel-base sheet alloys. Electrolytically etched; X250.

4341

Annealed		Heat-treated

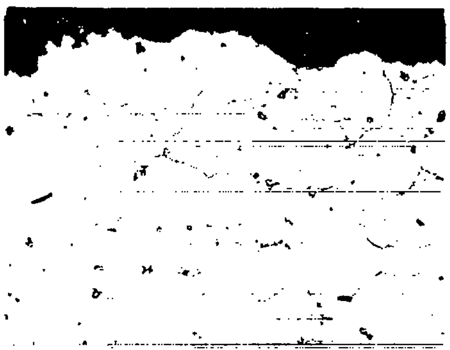


Before test

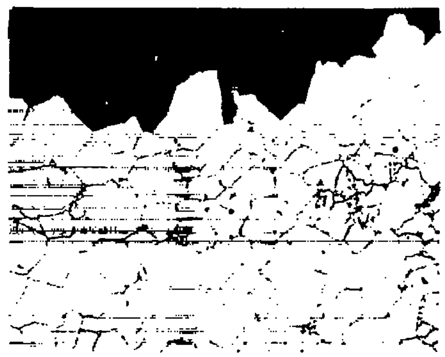


Etchant, 97 parts hydrochloric acid, 3 parts nitric acid, saturated with cupric chloride; hardness, Rockwell A-52

Etchant, 97 parts hydrochloric acid, 3 parts nitric acid, saturated with cupric chloride; hardness, Rockwell A-58

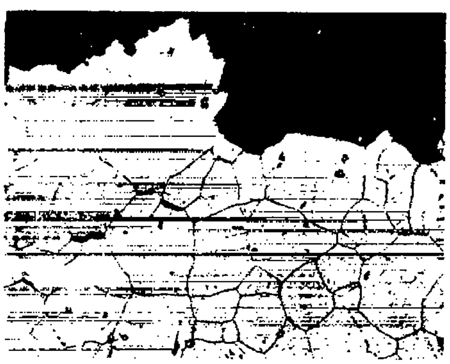


Stress-rupture tested at 1200° F

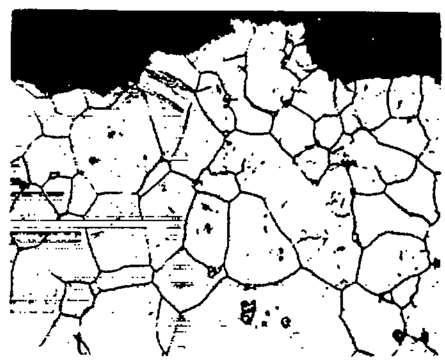


Fractured after 51.1 hours; etchant, 50 parts water, 40 parts hydrochloric acid, 10 parts nitric acid; hardness, Rockwell A-68

Fractured after 197.7 hours; etchant, 50 parts water, 40 parts hydrochloric acid, 10 parts nitric acid; hardness, Rockwell A-70



Stress-rupture tested at 1350° F



Fractured after 107.7 hours; etchant, 50 parts water, 40 parts hydrochloric acid, 10 parts nitric acid; hardness, Rockwell A-70

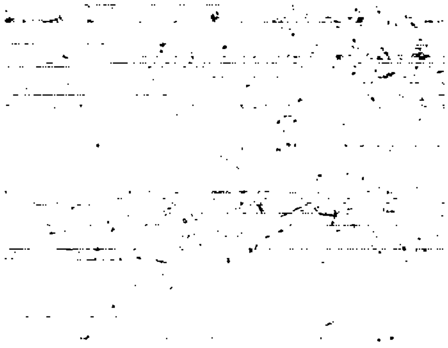
Fractured after 55.8 hours; etchant, 50 parts water, 40 parts hydrochloric acid, 10 parts nitric acid; hardness, Rockwell A-69

(b) Inconel 700. C-44049

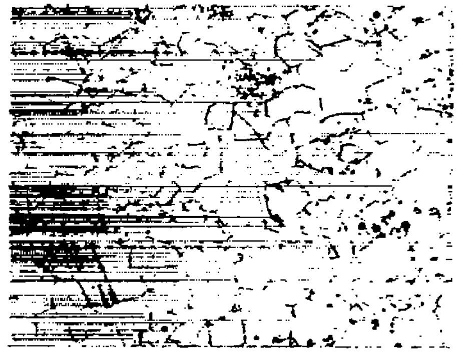
Figure 4. - Continued. Microstructures of nickel-base sheet alloys. Electrolytically etched; X250.

Annealed | Heat-treated

Before test

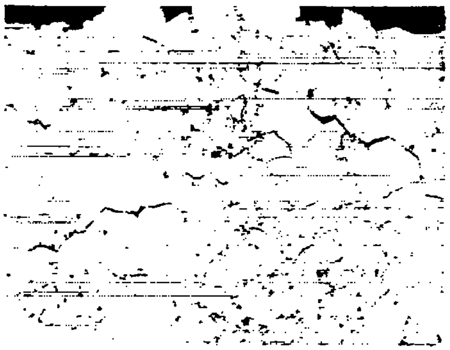


Etchant, 97 parts hydrochloric acid, 3 parts nitric acid, saturated with cupric chloride; hardness, Rockwell A-52

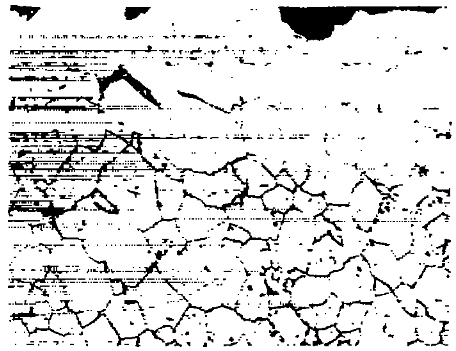


Etchant, 97 parts hydrochloric acid, 3 parts nitric acid, saturated with cupric chloride; hardness, Rockwell A-66

Stress-rupture tested at 1200° F

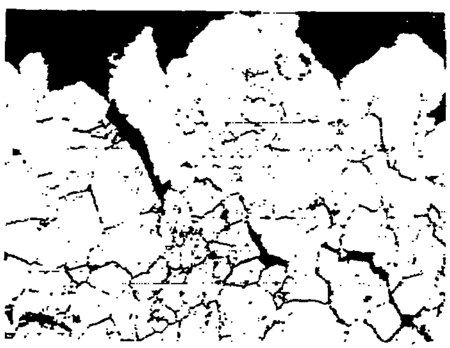


Fractured after 101.0 hours; etchant, 50 parts water, 40 parts hydrochloric acid, 10 parts nitric acid; hardness, Rockwell A-70

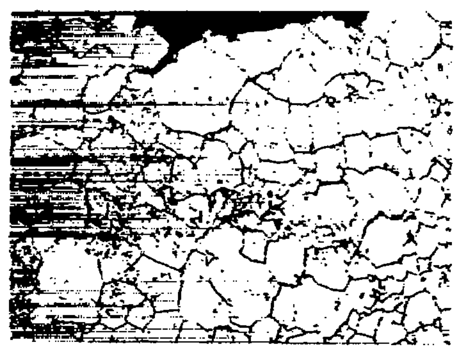


Fractured after 123.9 hours; etchant, 50 parts water, 40 parts hydrochloric acid, 10 parts nitric acid; hardness, Rockwell A-70

Stress-rupture tested at 1350° F



Fractured after 129.0 hours; etchant, 50 parts water, 40 parts hydrochloric acid, 10 parts nitric acid; hardness, Rockwell A-69



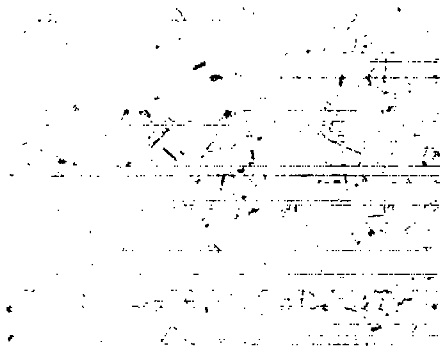
Fractured after 78.0 hours; etchant, 50 parts water, 40 parts hydrochloric acid, 10 parts nitric acid; hardness, Rockwell A-70

(c) Incoloy 901.

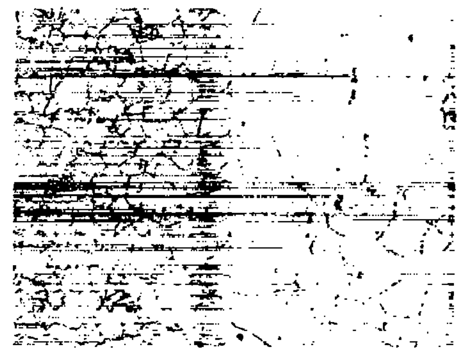
C-44047

Figure 4. - Continued. Microstructures of nickel-base sheet alloys. Electrolytically etched; X250.

Annealed



Heat-treated



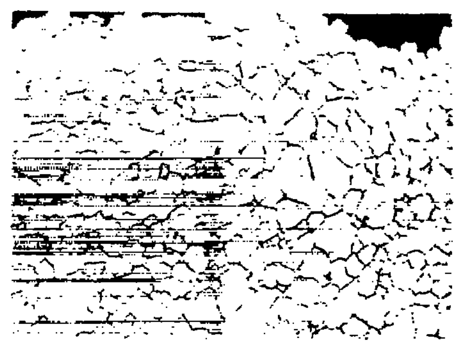
Before test

Etchant, 97 parts hydrochloric acid, 3 parts nitric acid, saturated with cupric chloride; hardness, Rockwell A-47

For service at 1200° F; etchant, 50 parts water, 40 parts hydrochloric acid, 10 parts nitric acid; hardness, Rockwell A-60

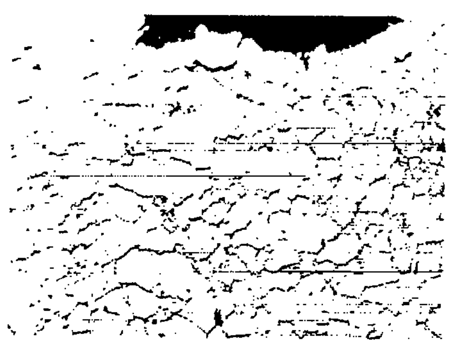
For service at 1350° F; etchant, 50 parts water, 40 parts hydrochloric acid, 10 parts nitric acid; hardness, Rockwell A-60

Stress-rupture tested at 1200° F



Fractured after 100.0 hours; etchant, 50 parts water, 40 parts hydrochloric acid, 10 parts nitric acid; hardness, Rockwell A-70

Fractured after 111.0 hours; etchant, 50 parts water, 40 parts hydrochloric acid, 10 parts nitric acid; hardness, Rockwell A-70



Stress-rupture tested at 1350° F

Fractured after 101.0 hours; etchant, 50 parts water, 40 parts hydrochloric acid, 10 parts nitric acid; hardness, Rockwell A-68

Fractured after 100.1 hours; etchant, 50 parts water, 40 parts hydrochloric acid, 10 parts nitric acid; hardness, Rockwell A-66

(d) Refractaloy 26.

C-44046

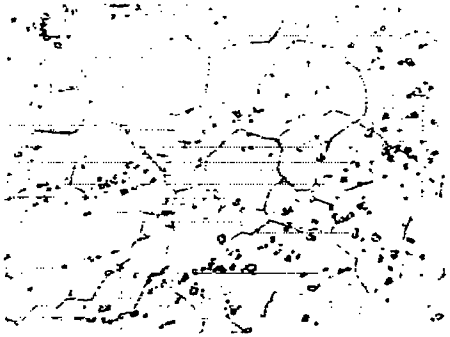
Figure 4. - Continued. Microstructures of nickel-base sheet alloys. Electrolytically etched; X250.

4341

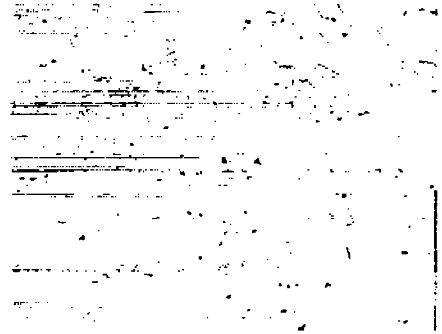
4341

Annealed | Heat-treated

Before test

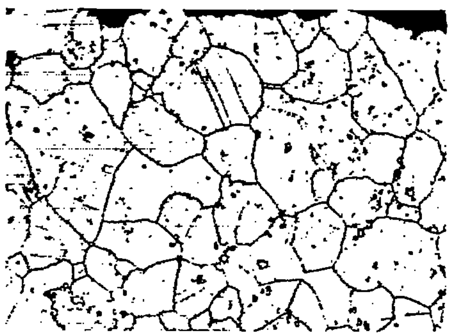


Hardness, Rockwell A-64



Hardness, Rockwell A-65

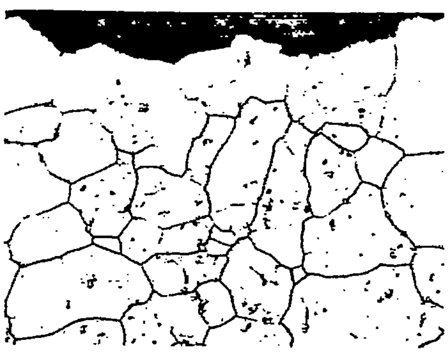
Stress-rupture tested at 1200° F



Fractured after 96.8 hours; hardness, Rockwell A-68

Fractured after 216.4 hours; hardness, Rockwell A-68

Stress-rupture tested at 1350° F



Fractured after 73.4 hours; hardness, Rockwell A-70

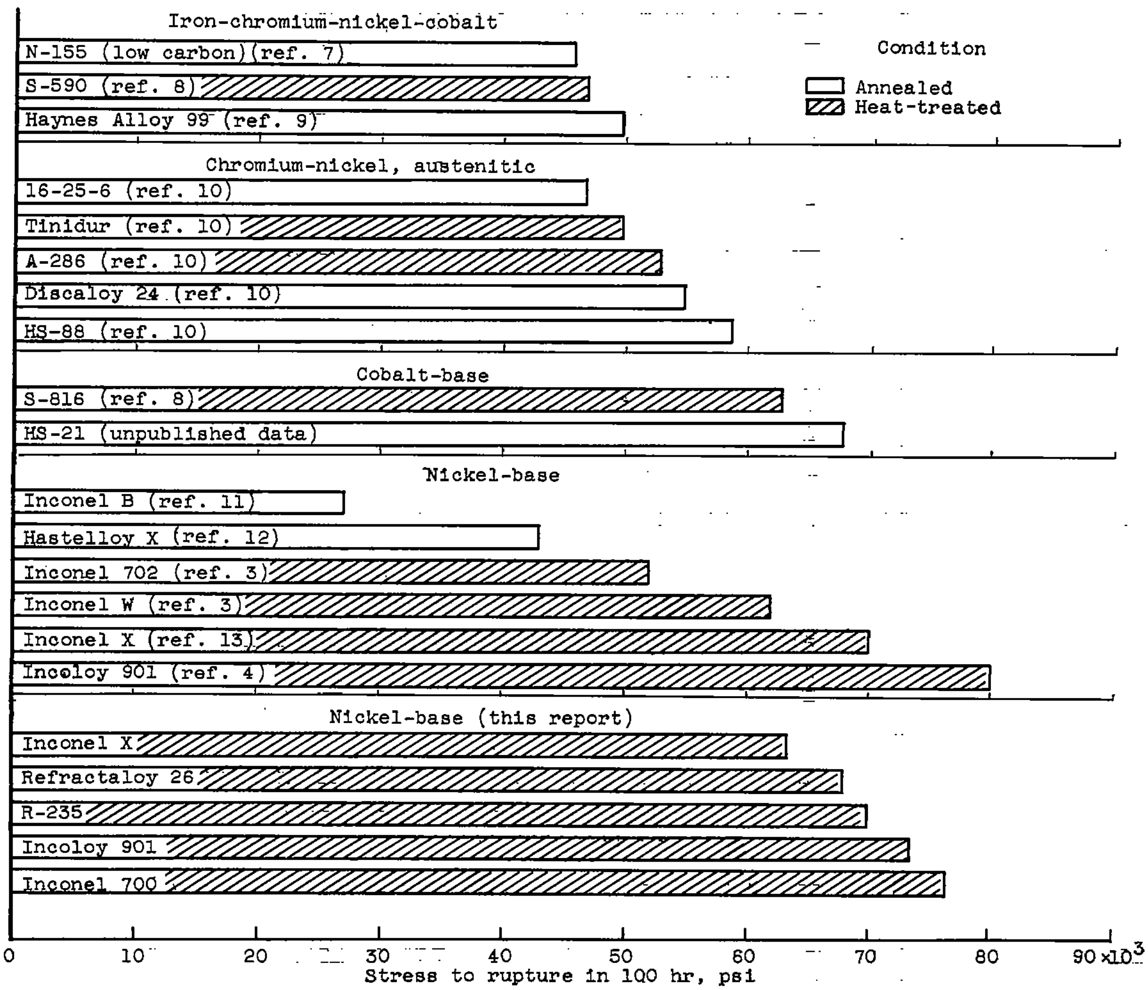
Fractured after 82.0 hours; hardness, Rockwell A-69

C-44045

(e) R-235. Etchant, 50 parts water, 40 parts hydrochloric acid, 10 parts nitric acid.

Figure 4. - Concluded. Microstructures of nickel-base sheet alloys. Electrolytically etched; X250.

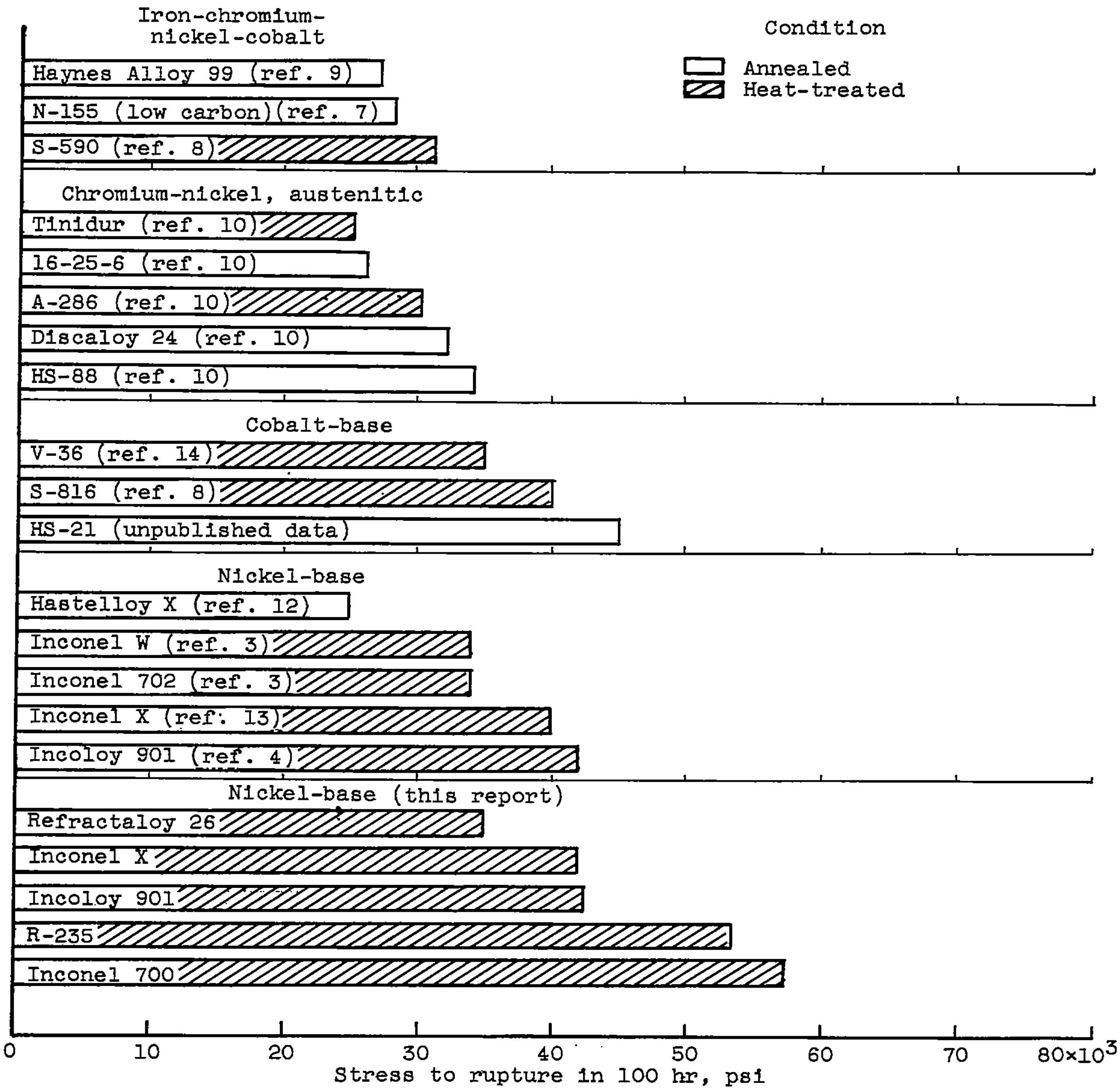
4341



(a) 1200° F.

Figure 5. - Comparison of 100-hour rupture strengths of sheet alloys at 1200° and 1350° F.

4341



(b) 1350° F.

Figure 5. - Concluded. Comparison of 100-hour rupture strengths of sheet alloys at 1200° and 1350° F.

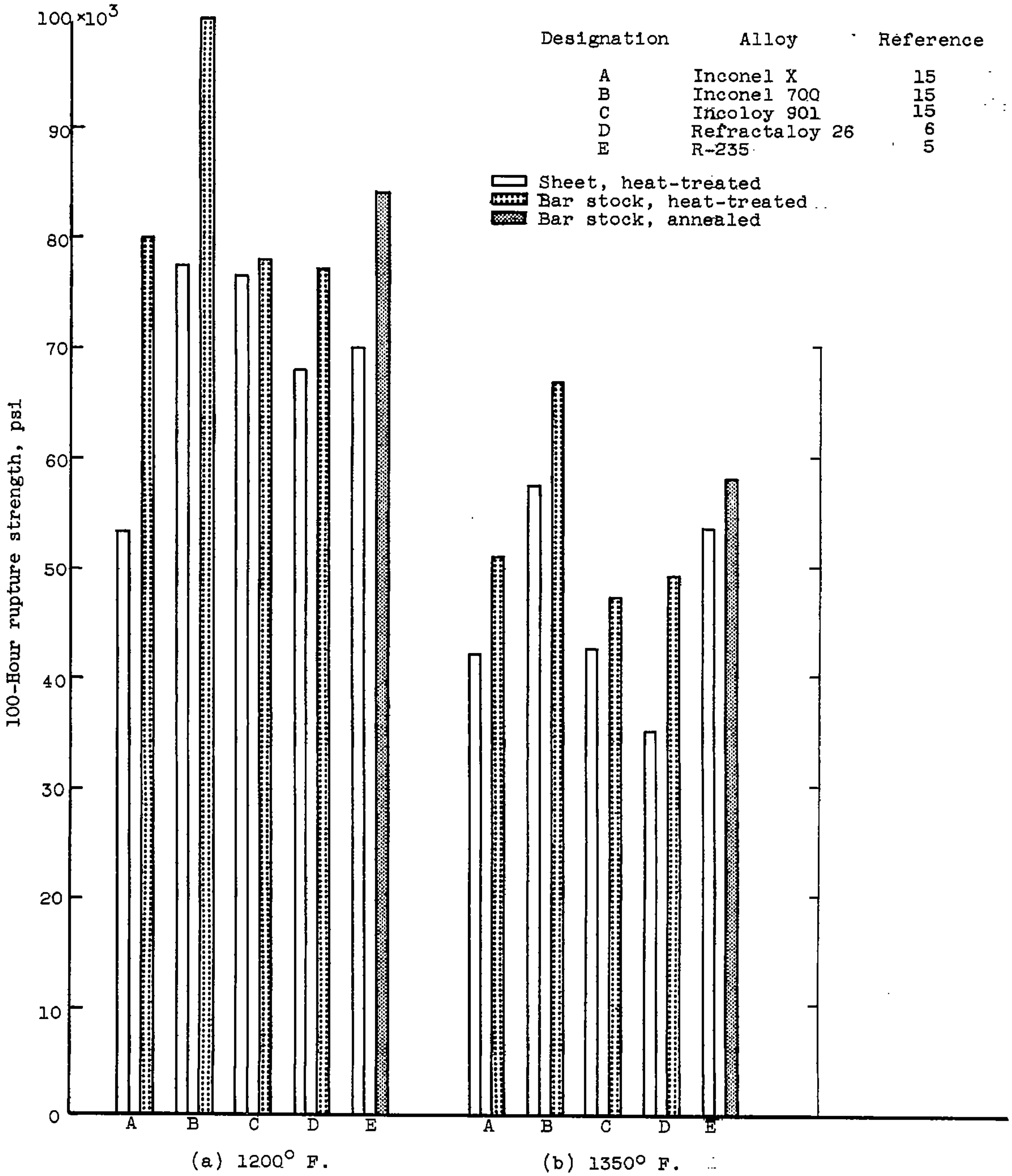


Figure 6. - Comparison of 100-hour rupture strengths of nickel-base alloys in sheet and bar forms at 1200° and 1350° F.

4341